Performances of Regional Model for Prediction Across Scales (MPAS) in Simulations of Typhoon Gaemi (2024) impinging Taiwan

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Outline

- Introduction
- Model and Experiment designs
- Results
- Conclusions
- References

Potential Vorticity (PV) budget

$$\frac{\partial q}{\partial t} = -\boldsymbol{U}\cdot\nabla q + \left(\frac{\boldsymbol{\omega_a}}{\rho}\cdot\nabla\right)\frac{d\theta_v}{dt} + \nabla\theta_v\cdot\frac{\nabla\rho\times\nabla p}{\rho^3} + \frac{1}{\rho}\nabla\theta_v\cdot(\nabla\times\boldsymbol{F}_r)$$

$$q = \frac{\omega_a}{\rho}\cdot\nabla\theta_v$$

$$\boldsymbol{\omega_a} = \omega + 2\Omega$$

$$\theta_v = \theta\left(\frac{1+\frac{q_v}{\varepsilon}}{1+\mathrm{Q}}\right)$$

$$\varepsilon = \frac{R_d}{R_v} = 0.622$$

Transform to the cylindrical coordinates

$$\frac{\partial q}{\partial t} = -u\frac{\partial q}{\partial r} - \frac{v}{r}\frac{\partial q}{\partial \lambda} - W\frac{\partial q}{\partial z} + H + S + T$$

H：Diabatic Heating
S：Solenoidal term
T：Turbulence

Wu & Wang (2000):

$$\left(\frac{\partial P}{\partial t}\right)_1 = -C_x\frac{\partial P_s}{\partial x} - C_y\frac{\partial P_s}{\partial y}$$

$$\boldsymbol{C_x} = -\frac{\sum_{i=1}^{N}\overline{\left(\frac{\partial \boldsymbol{P_s}}{\partial \boldsymbol{x}}\right)_i\left(\frac{\partial \boldsymbol{P}}{\partial \boldsymbol{t}}\right)_{1i}}}{\sum_{i=1}^{N}\overline{\left(\frac{\partial \boldsymbol{P_s}}{\partial \boldsymbol{x}}\right)_i}^2} \qquad \boldsymbol{C_y} = -\frac{\sum_{i=1}^{N}\overline{\left(\frac{\partial \boldsymbol{P_s}}{\partial \boldsymbol{y}}\right)_i\left(\frac{\partial \boldsymbol{P}}{\partial \boldsymbol{t}}\right)_{1i}}}{\sum_{i=1}^{N}\overline{\left(\frac{\partial \boldsymbol{P_s}}{\partial \boldsymbol{y}}\right)_i}^2}$$

Introduction

- Typhoon Gaemi (2024) followed a looping track offshore near northern Taiwan before making landfall, bringing severe rainfall.
- Chi et al. (2025) found that MPAS with global mesh 60-15-1km can capture the looping motion of typhoon Gaemi.
- This study aims to explore how well regional MPAS captures the track and intensity of typhoon Gaemi.
- Different physic schemes were tested for an optimal simulation of Gaemi’s track looping and motion in this study.

Experiment Designs

- Regional MPAS model (version 8.0.1)
- Simulate from 0000 UTC 23 July to 1200 UTC 25 July 2024
- The model was initialized and forced at the lateral boundary conditions by using NCEP reanalysis data.

Parameterization	Scheme
Convection	Modified version of scale-aware Grell-Freitas
Microphysics	WSM6
Land surface	Noah
Boundary layer	YSU
Surface layer	Monin-Obukhov
Radiation, LW	RRTMG
Radiation, SW	RRTMG
Cloud fraction for radiation	Xu-Randall
Gravity wave drag by orography	YSU

Table 1. Physics schemes used in CTL simulation

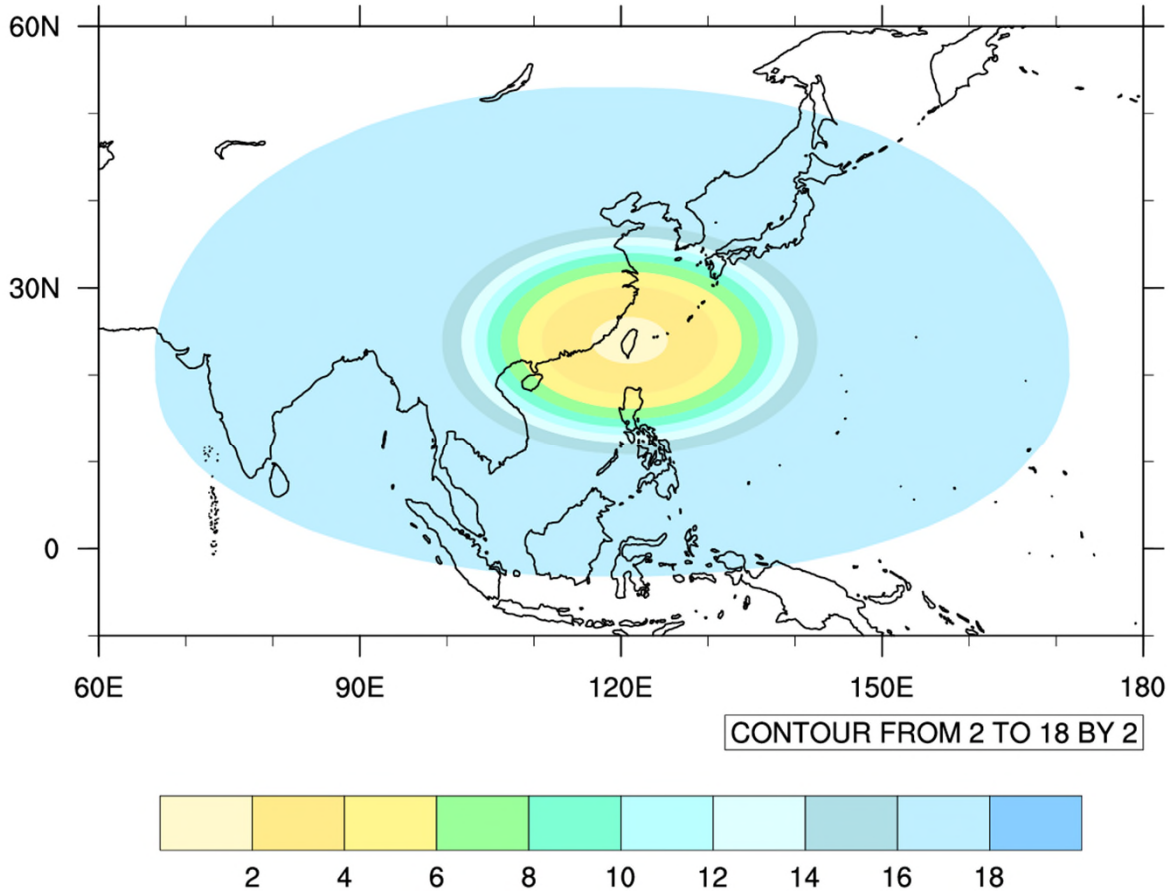


Fig 1. The variable-resolution mesh (20-2 km) used in the MPAS simulation with the area of the highest resolution targeted over Taiwan

Result

Track

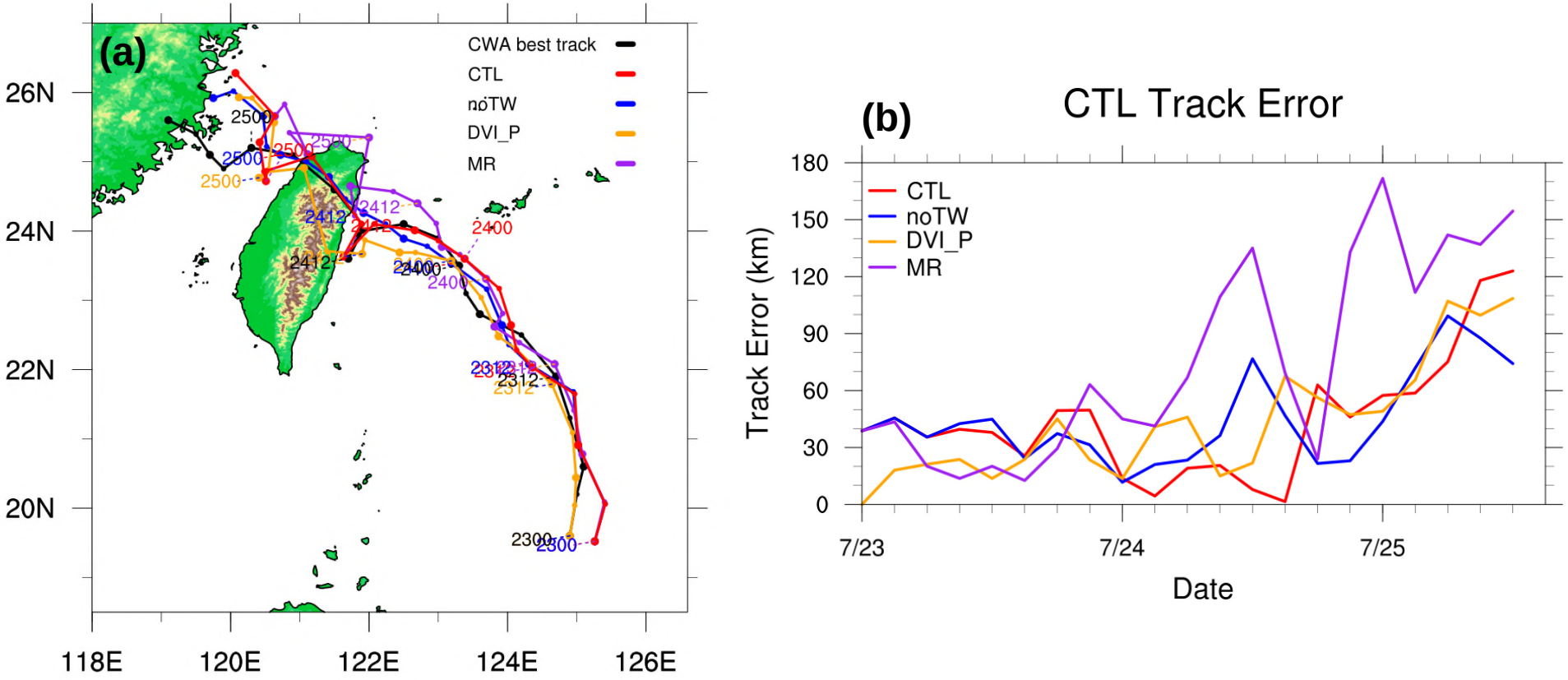


Fig 2. (a) CWA best track (black), simulated track for CTL (red), noTW (blue), DVI_P (orange), MR (purple) during the forecast period from 0000 UTC 23 July to 1200 UTC 25 July 2024.
(b) The simulated track errors for different experiments.

Intensity

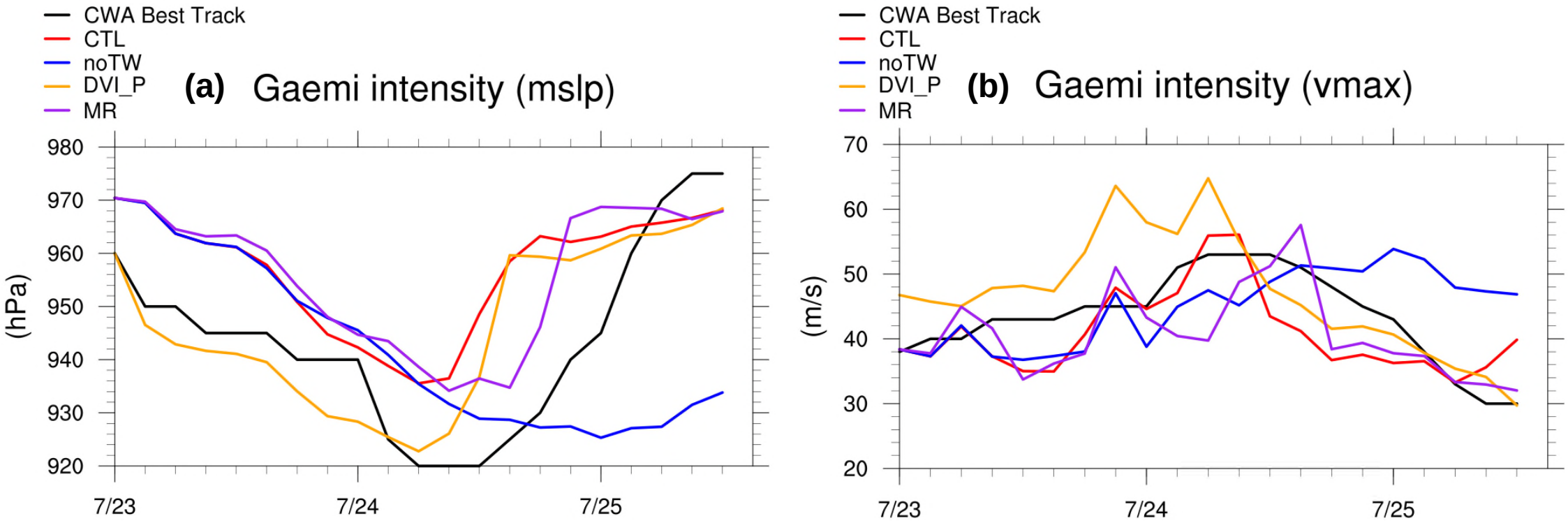


Fig 3. Simulated intensity for CTL (red), noTW (blue), DVI_P (orange), MR (purple) with CWA best track (black) during the forecast period from 0000 UTC 23 July to 1200 UTC 25 July 2024.
(a) Simulated minimum sea-level pressure and **(b)** maximum 10-m wind speed (m s^{-1}), respectively.

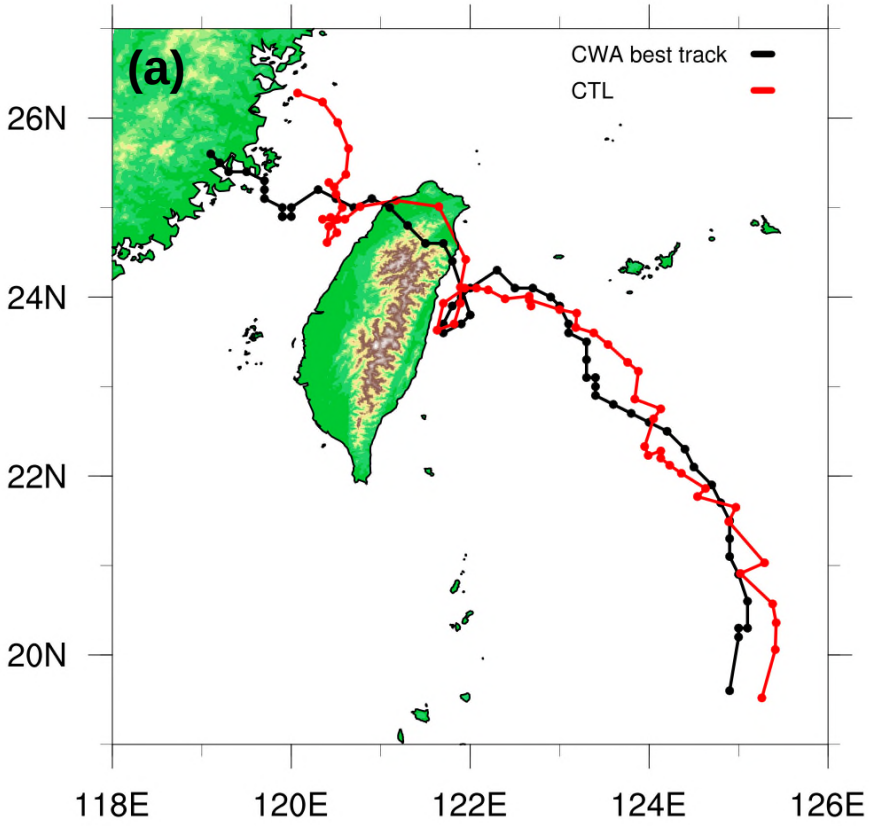


Fig 4. The simulated track evolution of CTL with hourly output

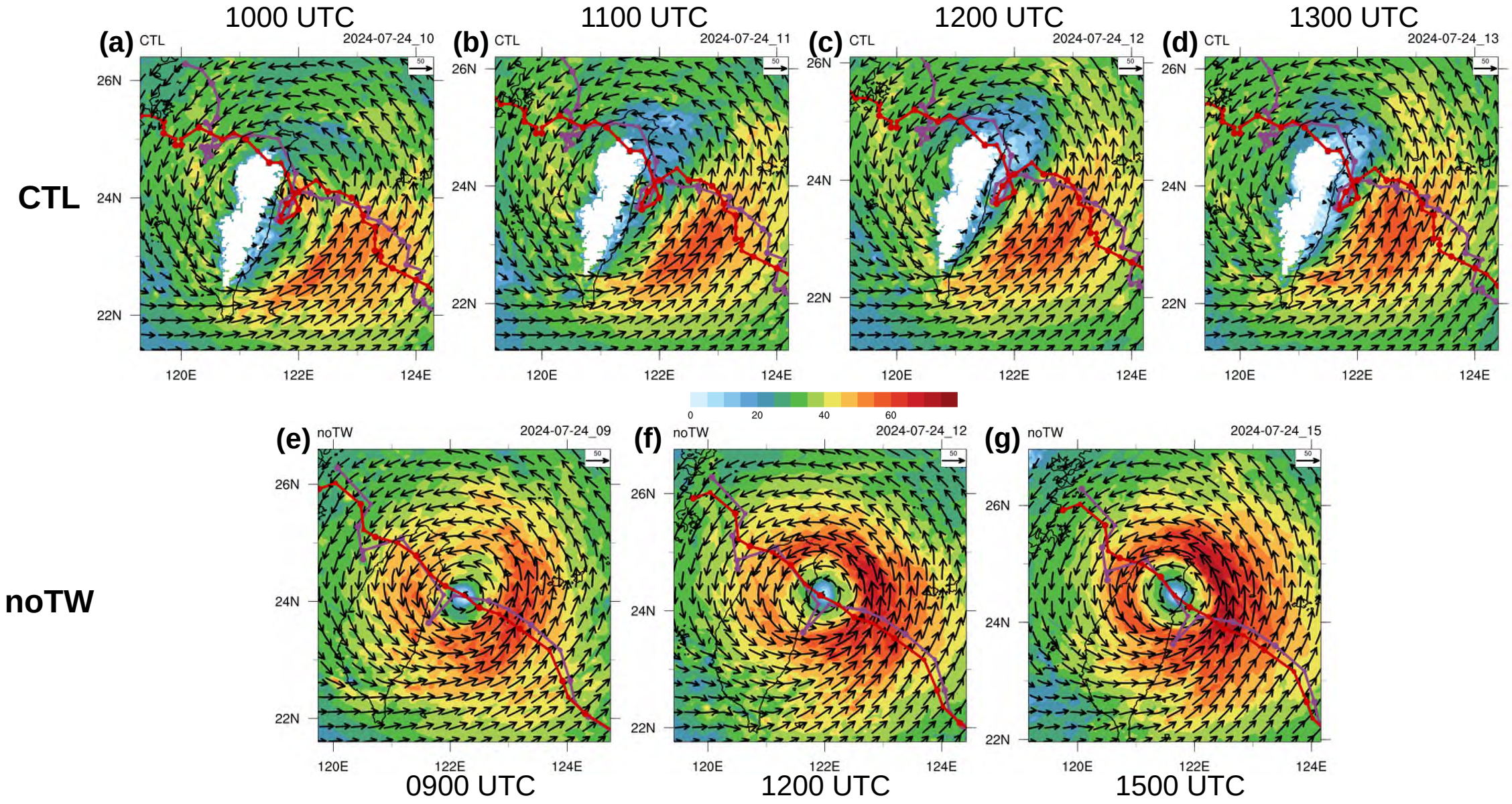


Figure 5. The horizontal wind field (m s^{-1}) at 850 hPa for **CTL** at **(a)** 1000 UTC 24 **(b)** 1100 UTC 24 **(c)** 1200 UTC 24 **(d)** 1300 UTC 24 and for **noTW** at **(e)** 0900 UTC 24 **(f)** 1200 UTC 24 **(g)** 1500 UTC 24

Transverse circulation wind field for CTL

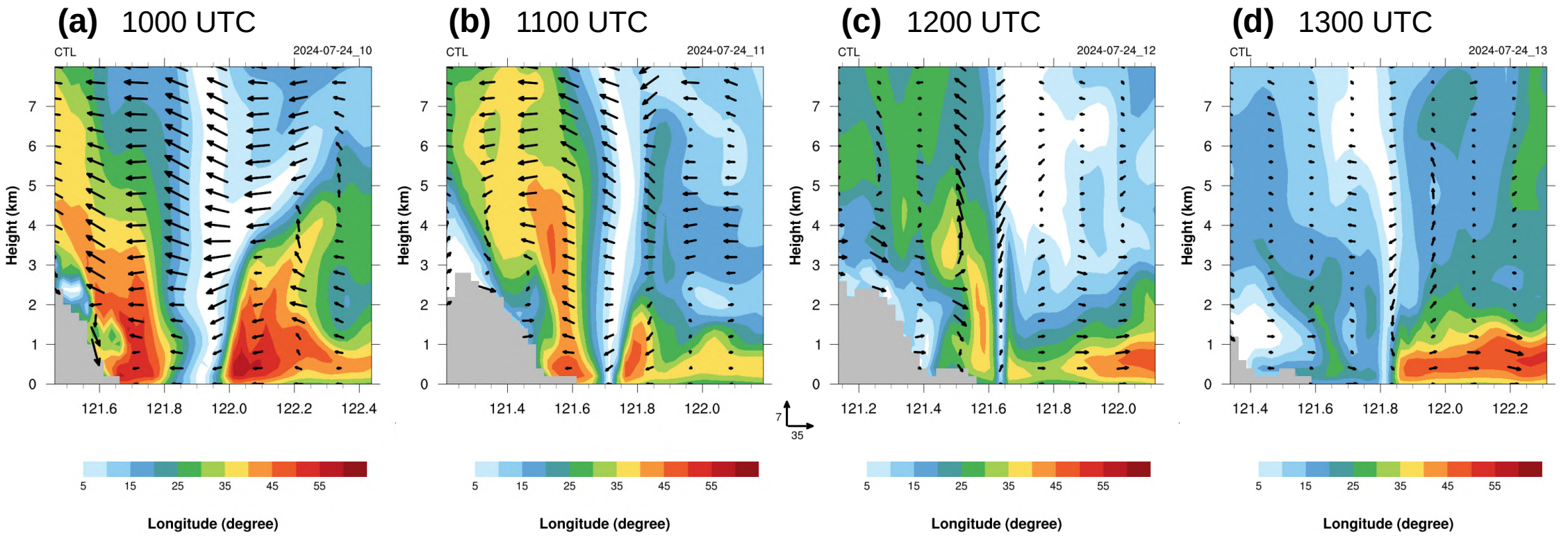


Figure 6. The radial and vertical wind components (vectors; m s^{-1}) of the transverse circulation at the east-west cross-section through the typhoon center, overlapped with tangential velocity (shaded colors; m s^{-1}) at **(a)** 1000 UTC 24 **(b)** 1100 UTC 24 **(c)** 1200 UTC 24 **(d)** 1200 UTC 24.

PV budget analysis

- In this study, PV budget analysis is averaged in 1-8km height and within radius 150km

- Analysis time period： 0900-1500 UTC 24 July 2024

PV budget analysis

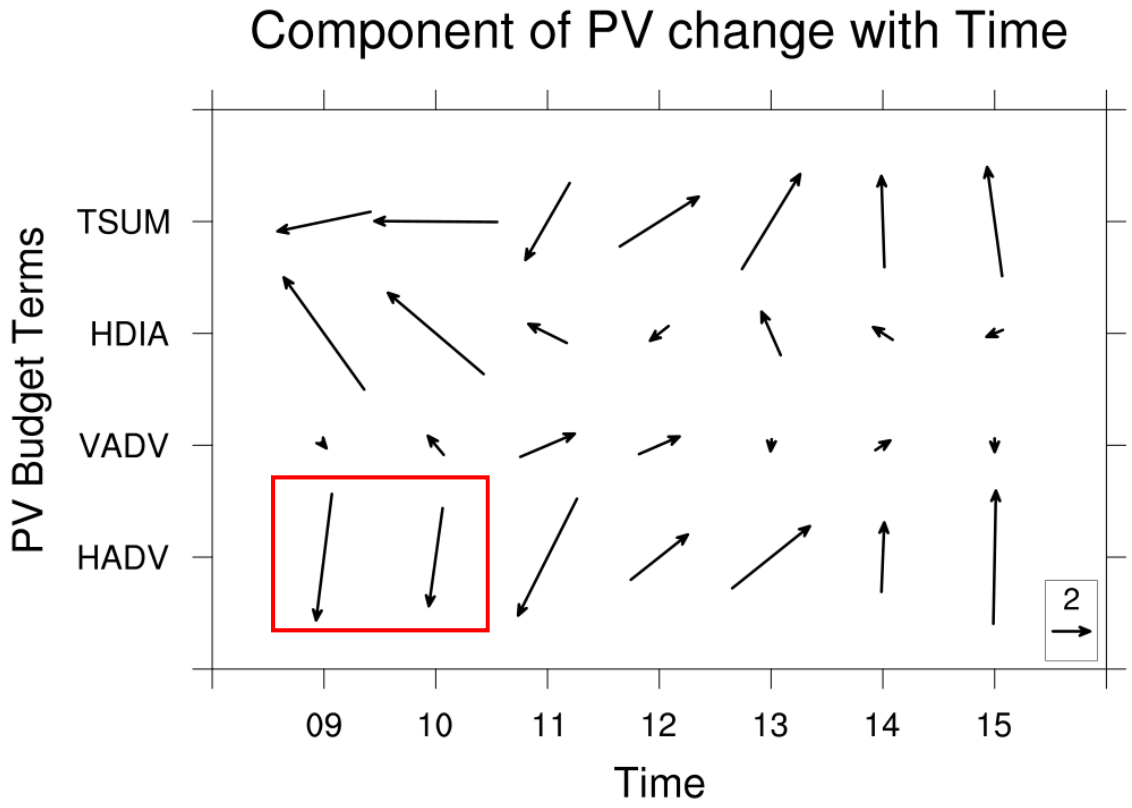
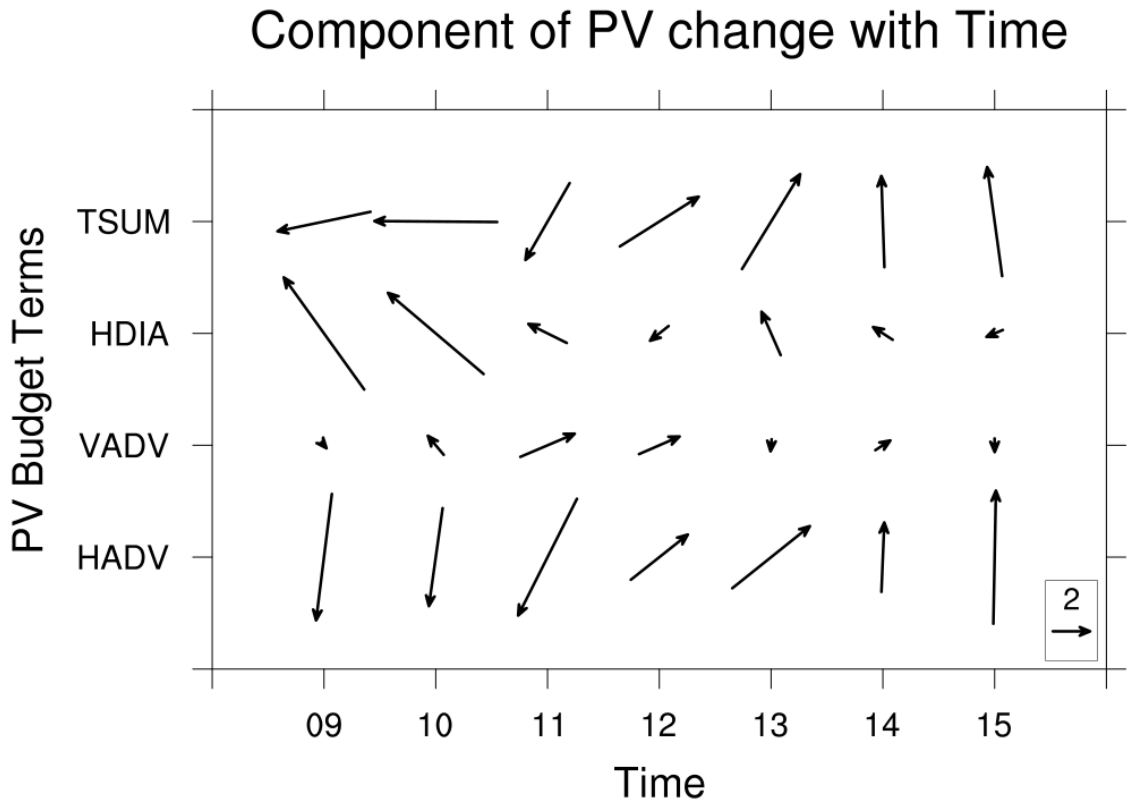


Figure 7. Time series plots of PV tendency contributions, including total sum (TSUM), diabatic heating (HDIA), vertical advection (VADV), horizontal advection (HADV).

PV budget analysis



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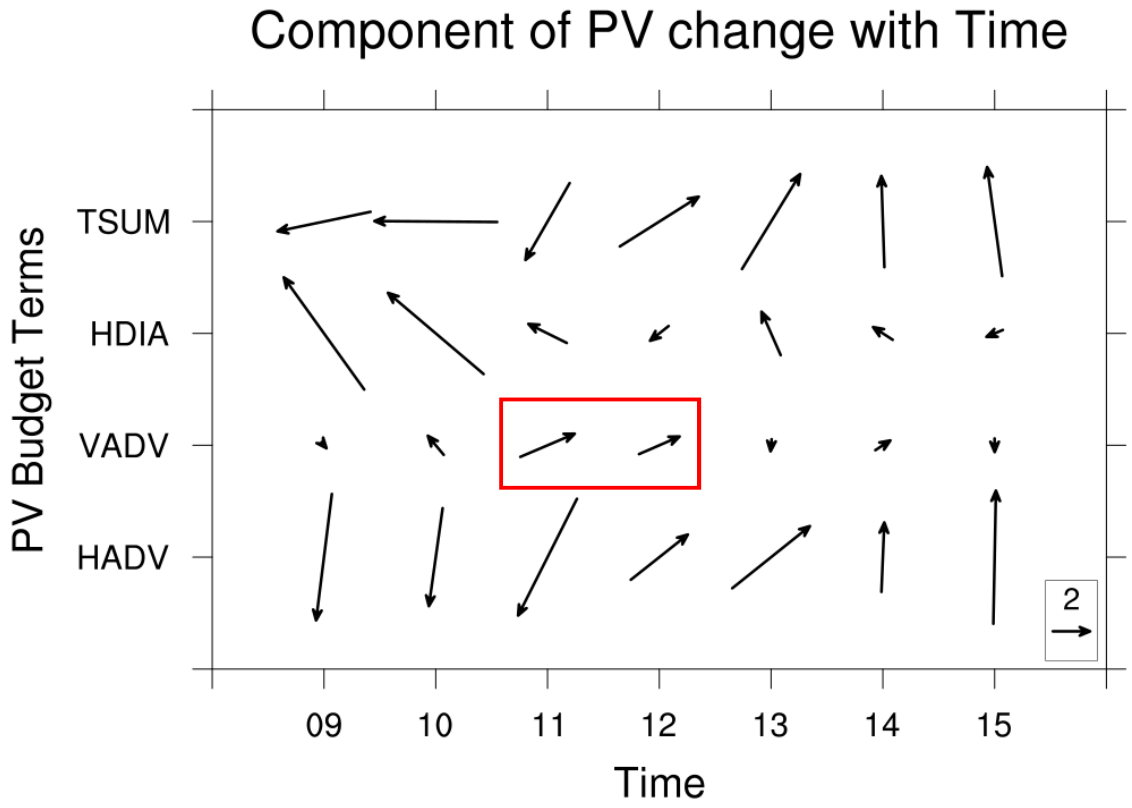
PV budget analysis



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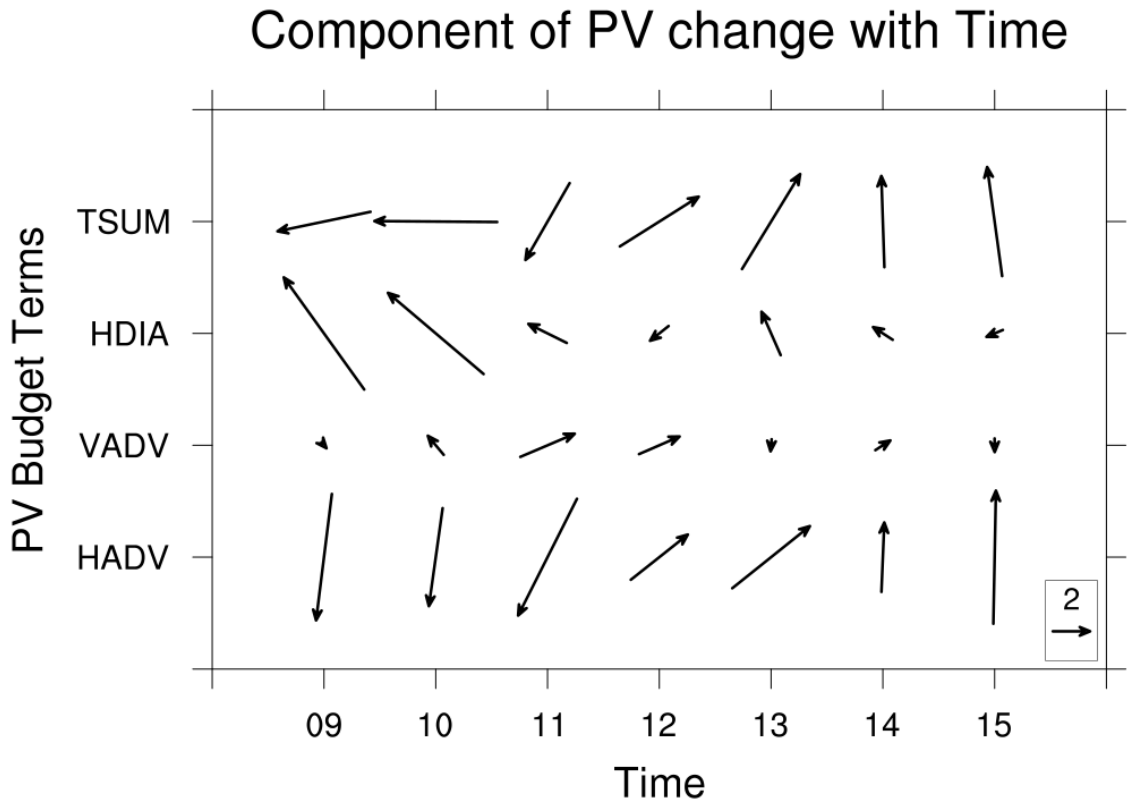
PV budget analysis



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Difference in WN-1 flow

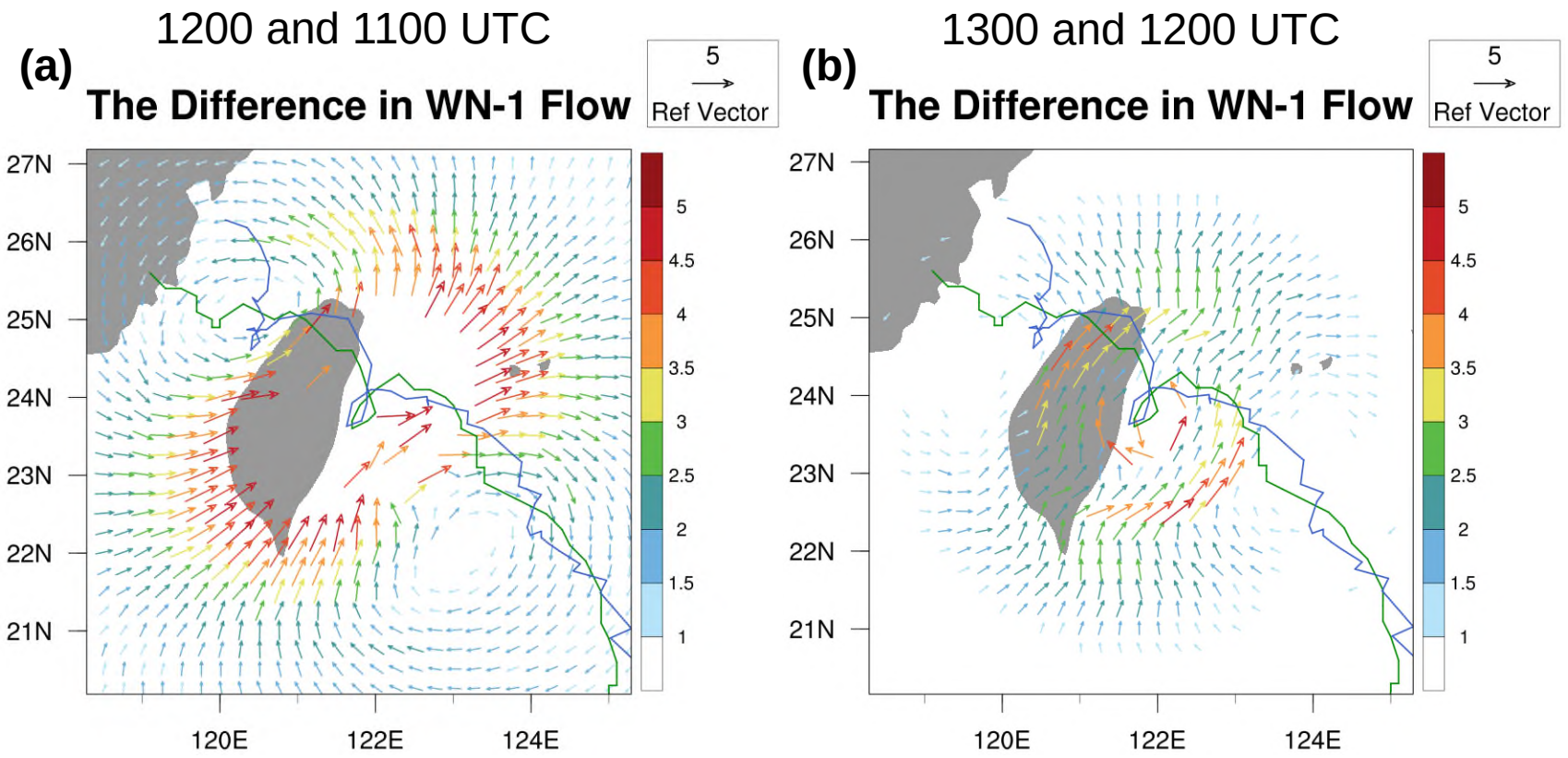


Fig 8. The difference in WN-1 flow averaged in 1–8-km height and within a 150-km radius of the TC center between **(a)** 1200 UTC 24 July and 1100 UTC 24 July **(b)** 1300 UTC 24 July and 1200 UTC 24 July

Accumulated Rainfall

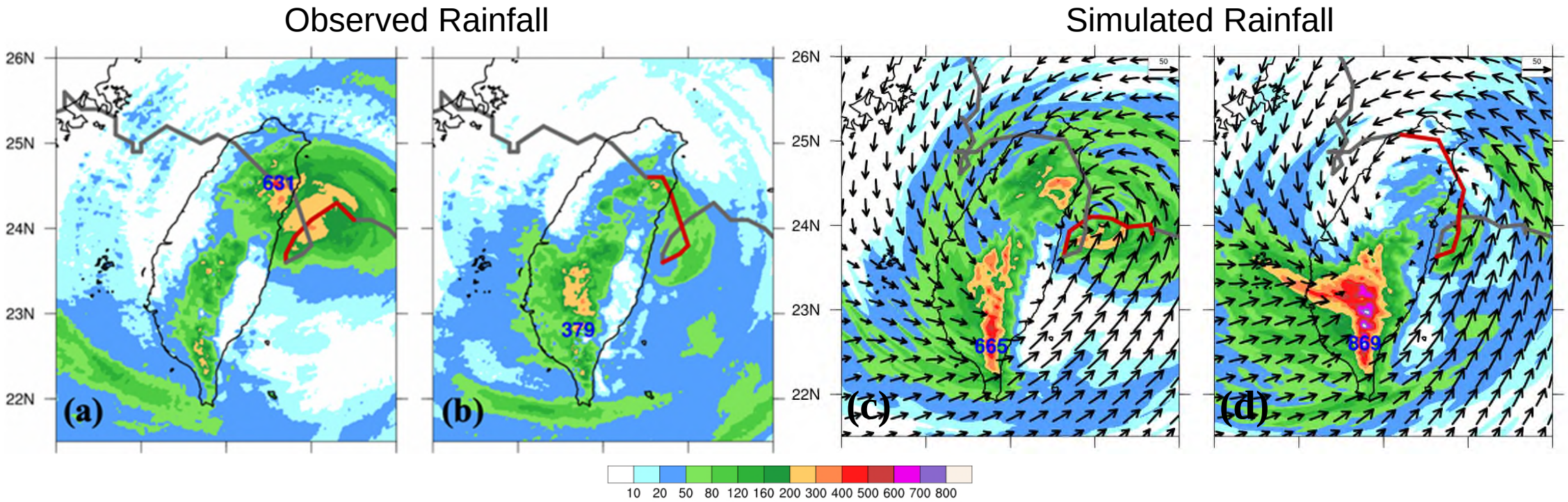


Fig 9. (a) Observed rainfall (mm) during 0600-1200 UTC on 24 July 2024 , along with the CWA best track. **(b)** As in **(a),** but during 1200-1800 UTC on 24 July 2024. **(c)** and **(d)** are as in **(a)** and **(b)**, respectively, but for the simulated result of CTL with overlapped horizontal wind (m s^{-1}) at 200-m height at the middle time of the period.

Conclusion

- Regional MPAS simulations can capture the looping track of Typhoon Gaemi that is not induced as the CMR is removed in the noTW experiment.
- The analysis of deep-layer wavenumber-one PV budget indicates that horizontal PV advection dominates the track looping, while somewhat modified by the vertical PV advection with induced northward and offshore translation during the southward vortex movement.
- Regional MPAS simulations obtain reasonable rainfall distributions but overestimate the total rainfall with a further southward maximum at south Taiwan during the looping period, as compared to the observed rainfall and other modeling results with TWRF (Chi et al., 2025)

References

- Chi, Y.-S., C.-Y. Huang*, L.-F. Hsiao, D.-S. Chen, S.-H. Sha, K. Hsu, and P.-L. Chang, 2025: A numerical study for the looping track and severe rainfall over south Taiwan associated with Typhoon Gaemi (2024). Geoscience Letters, submitted, in revision.

Thanks for Listening

Taking its azimuthal mean gives

$$\frac{\partial \overline{q+q'}}{\partial t} = -\overline{(\overline{u}+u')\frac{\partial(\overline{q}+q')}{\partial r}} - \overline{\frac{(\overline{v}+v')}{r}\frac{\partial(\overline{q}+q')}{\partial \lambda}} - \overline{(\overline{w}+w')\frac{\partial(\overline{q}+q')}{\partial z}} + \overline{H} + \overline{S} + \overline{T}$$

Can be reduced to

$$\frac{\partial \overline{q}}{\partial t} = -\overline{u}\frac{\partial \overline{q}}{\partial r} - \overline{w}\frac{\partial \overline{q}}{\partial z} - \overline{u'\frac{\partial q'}{\partial r}} - \overline{\frac{v'}{r}\frac{\partial q'}{\partial \lambda}} - \overline{w'\frac{\partial q'}{\partial z}} + \overline{H} + \overline{S} + \overline{T}$$

Transport of mean PV by mean transverse circulation

Mean advection of eddy PV

Regional MPAS

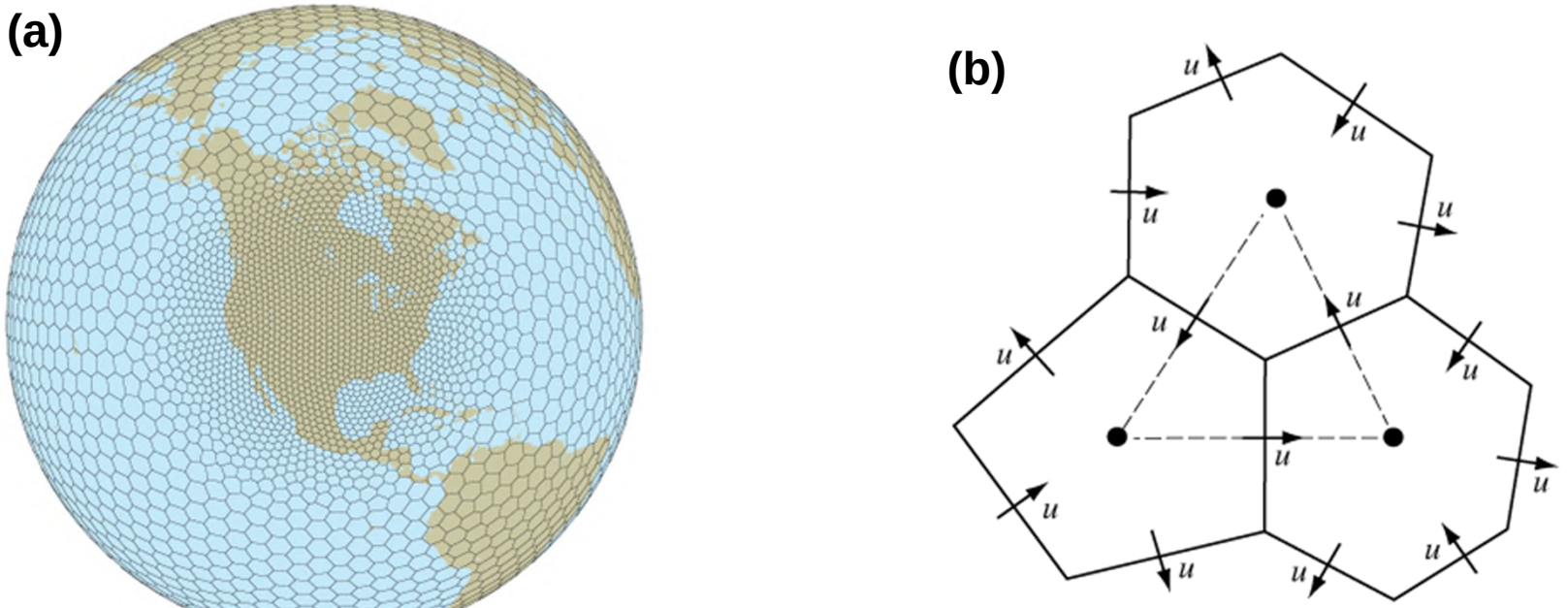
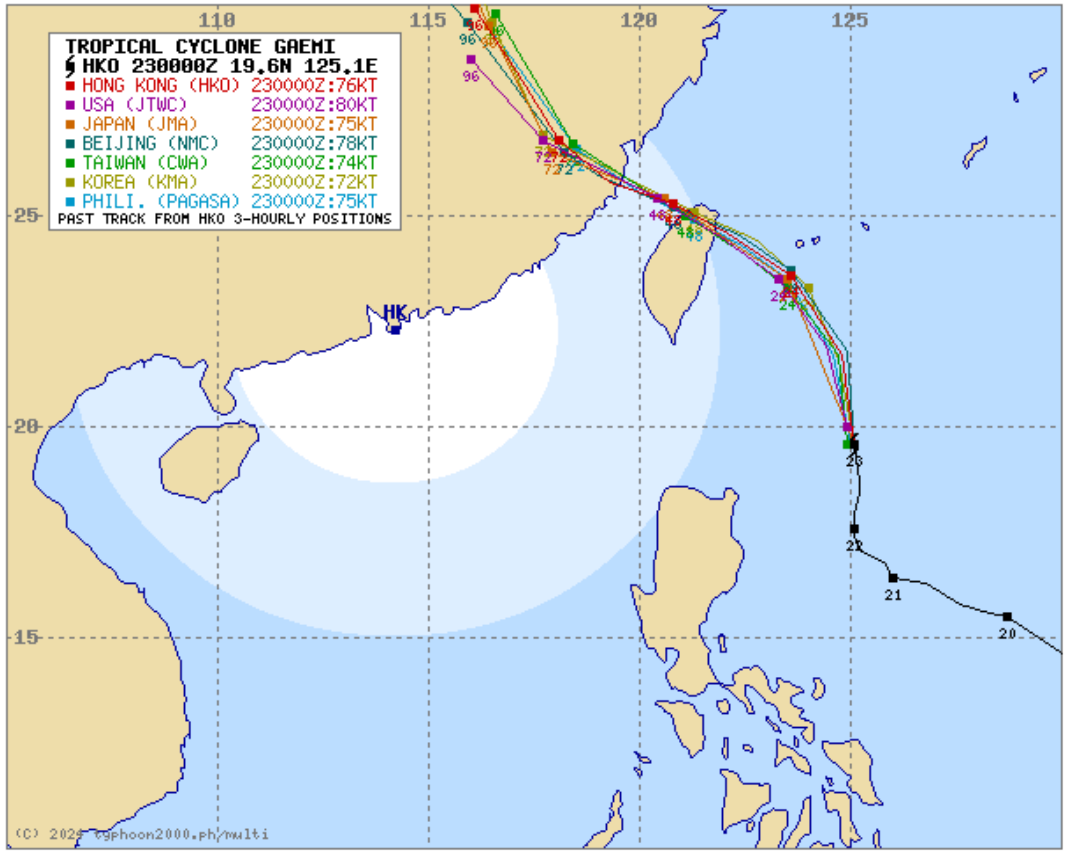


Fig 1. (a) A variable resolution MPAS Voronoi mesh. **(b)** C-grid staggered variables on the horizontal Voronoi mesh.


TROPICAL CYCLONE GAEMI
HKO 230000Z 19.6N 125.1E
HONG KONG (HKO) 230000Z:76KT
USA (JTWC) 230000Z:80KT
JAPAN (JMA) 230000Z:75KT
BEIJING (NMC) 230000Z:78KT
TAIWAN (CWA) 230000Z:74KT
KOREA (KMA) 230000Z:72KT
PHILI. (PAGASA) 230000Z:75KT
PAST TRACK FROM HKO 3-HOURLY POSITIONS
110
115
120
125
25
20
15
HK
(C) 2025 typhoon2000.ph/multi

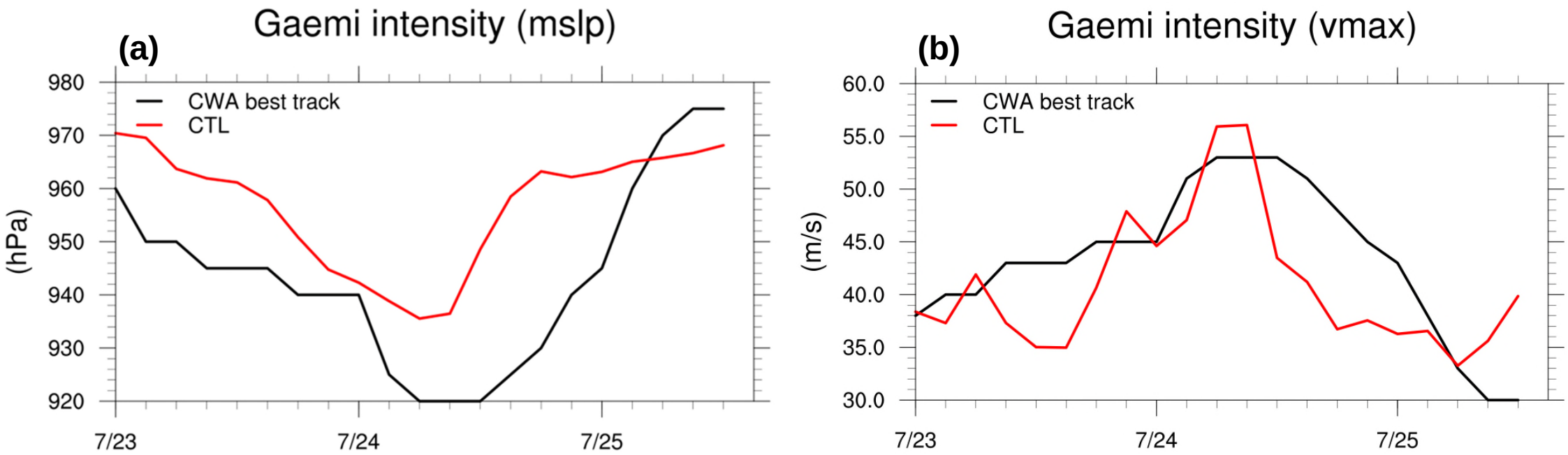
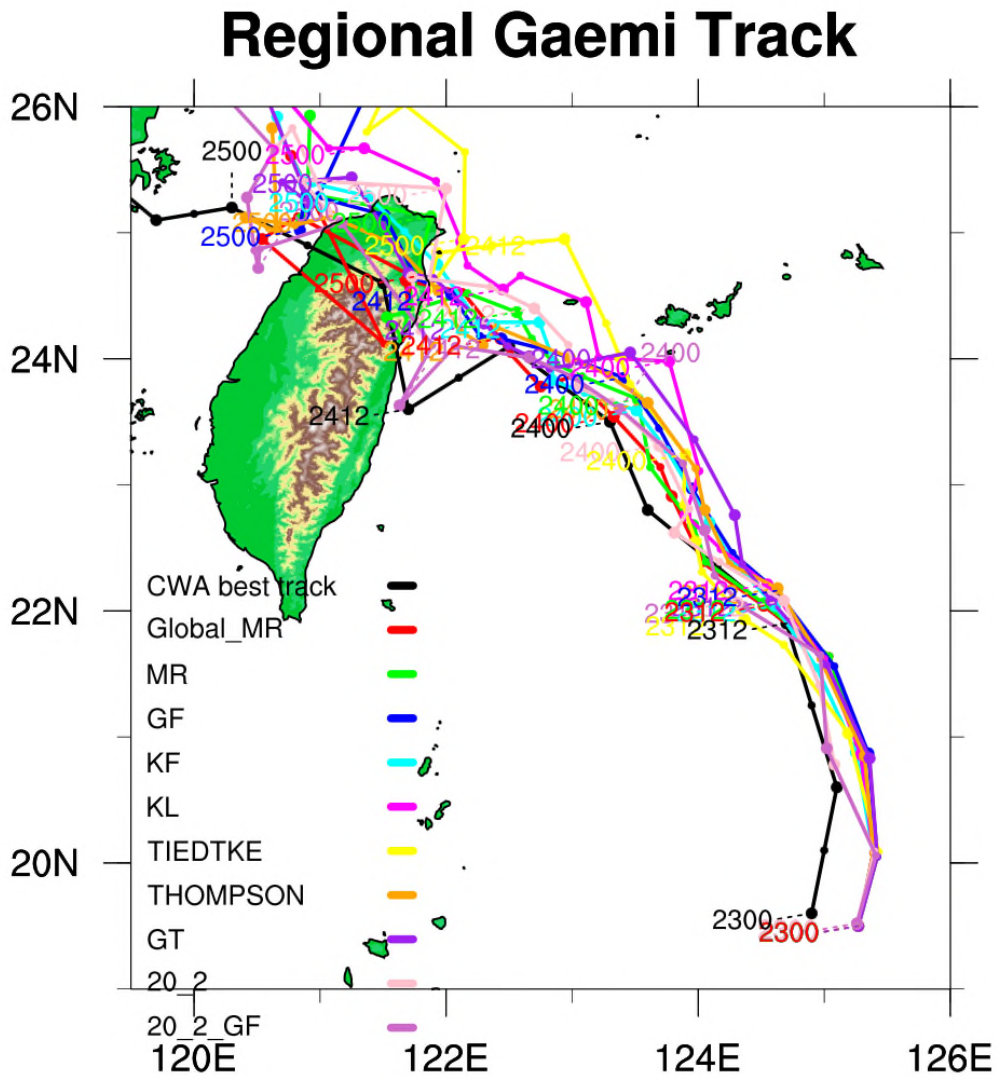


Fig . The observed best track (black) from CWA and simulated intensity evolution of CTL for **(a)** Minimum sea level pressure **(b)** Maximum wind speed.

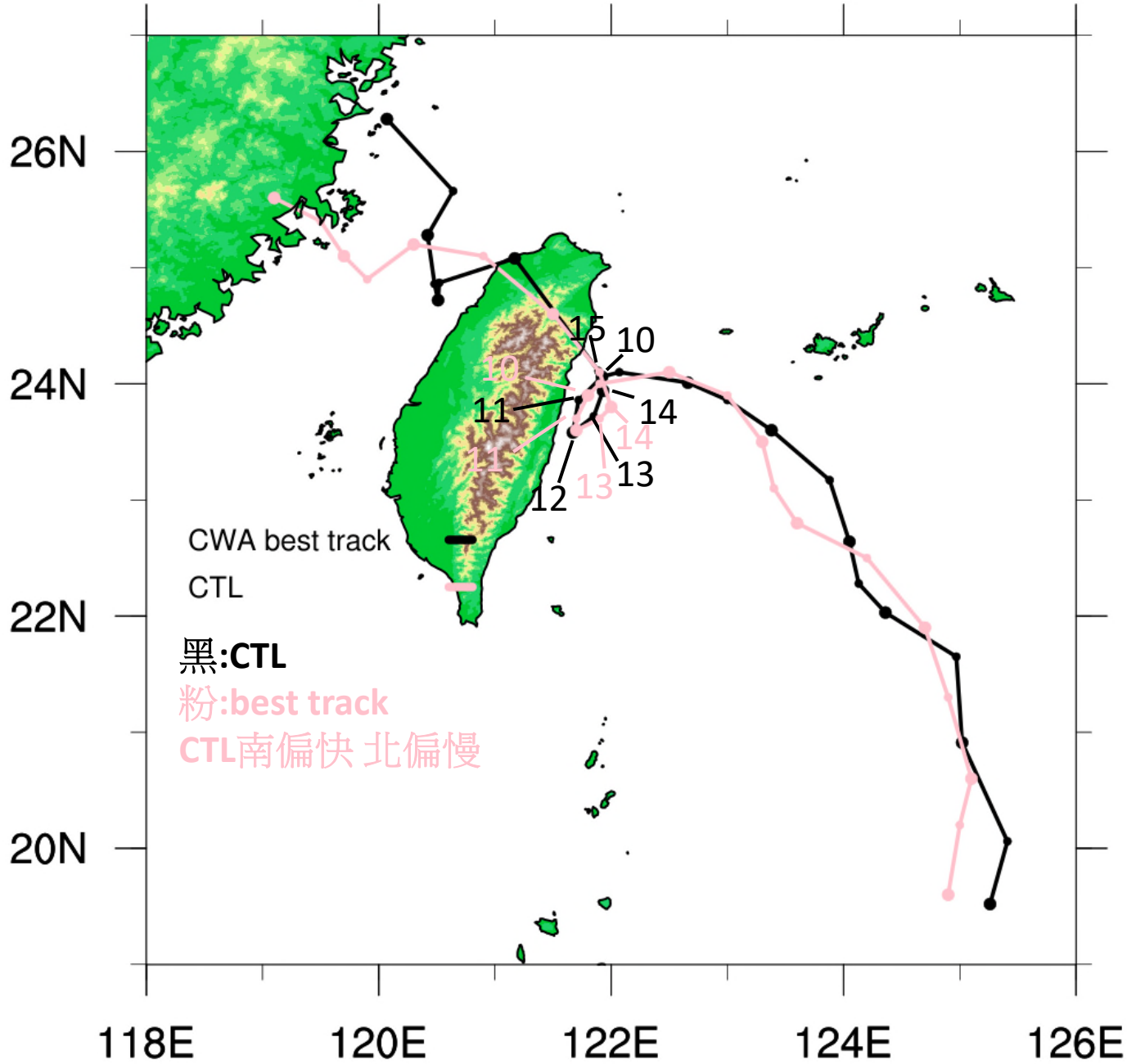
初始時間:072300

相比上次多了一個run
粉色的用氣象署20-2km mesh
物理參數化是mesoscale reference

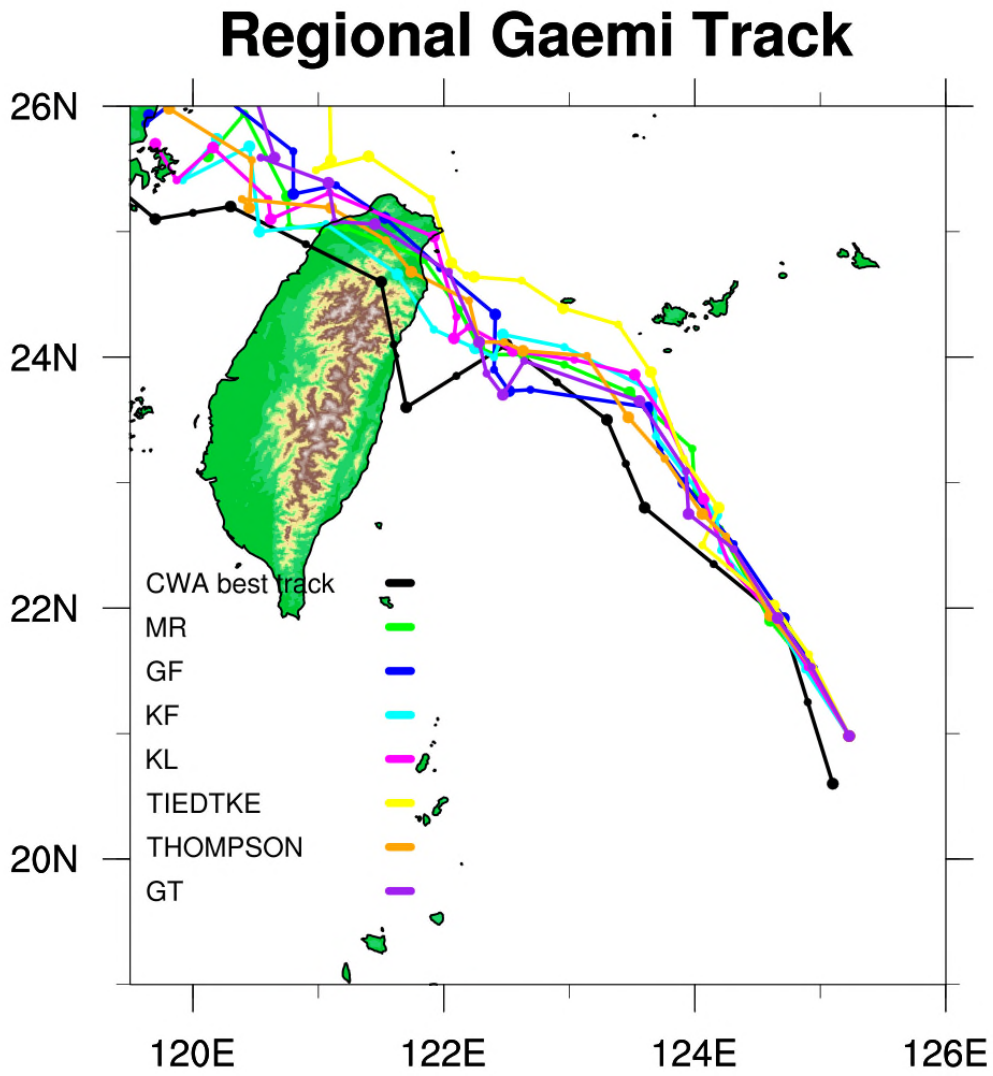


初始時間:072300

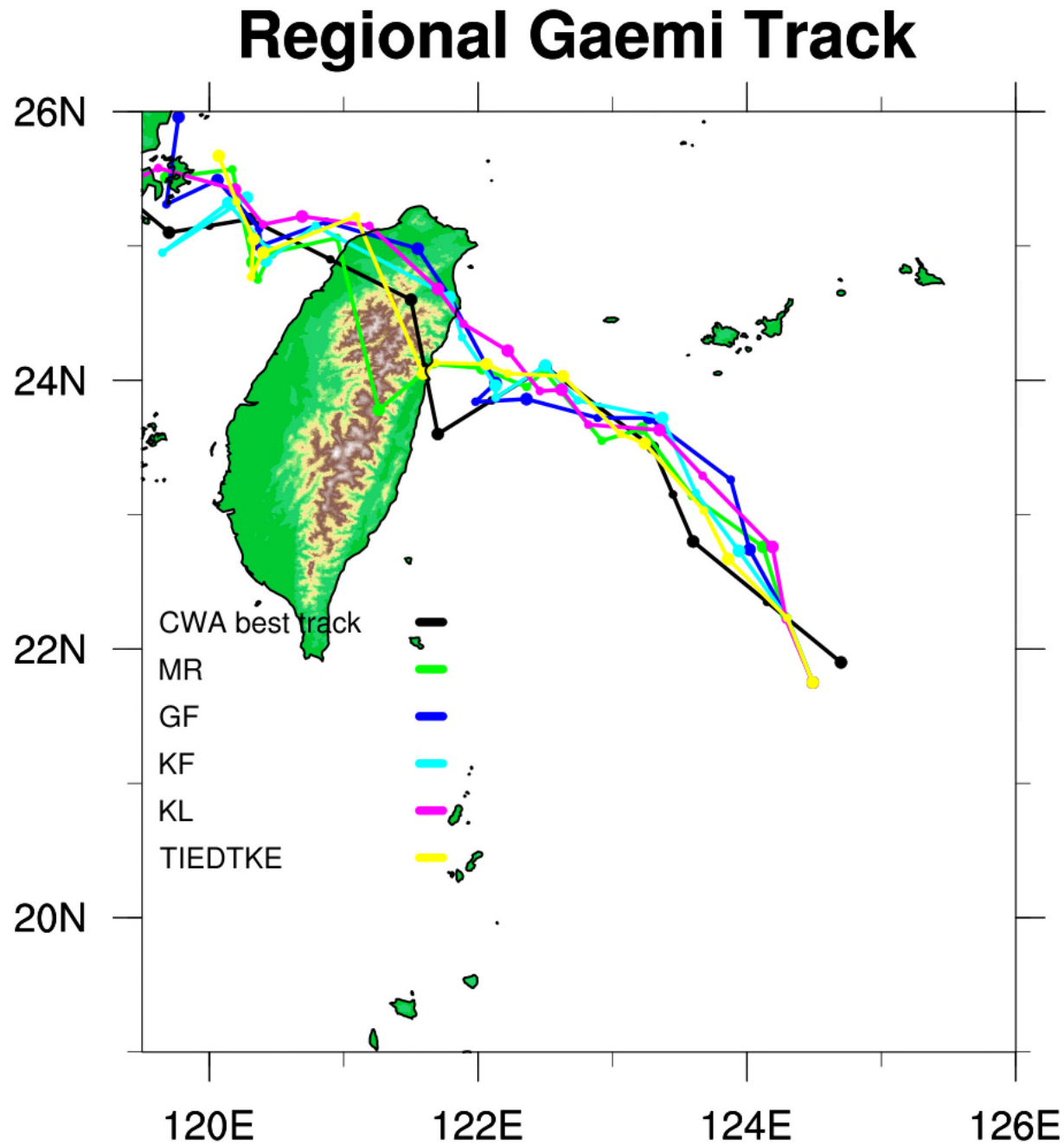
Regional Gaemi Track



初始時間:072306


Regional Gaemi Track
26N
24N
22N
20N
120E
122E
124E
126E
CWA best track
MR
GF
KF
KL
TIEDTKE
THOMPSON
GT

初始時間:072312


Regional Gaemi Track
26N
24N
22N
20N
120E
122E
124E
126E
CWA best track
MR
GF
KF
KL
TIEDTKE